Voltage Regulating Apparatus
Reference Data
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COOPER POWER
SERIES

Determination of Regulator Compensator Settings

Contents

General

Feeder regulators are equipped to automatically and continuously correct circuit voltages according to locally established practices. Procedures for checking and setting the control devices are described in detail in related instructions on the control unit.

Also, however, it is necessary that line-drop compensation values be determined and applied to the compensator. These involve the circuit calculations described in this document.

Advantages Of Feeder Regulators

Correctly applied and accurately adjusted, regulators can be justified economically because they provide more satisfactory service to the light and power consumer.

It can be demonstrated that maintaining a high quality of voltage control will result in a higher level of permissible loading on feeders, and will defer investment for rebuilding or adding capacity. Because of higher average voltage and, therefore, kw/hr usage, an increase in revenue will accrue.

It is obvious that a more uniform voltage level will improve operation of lights, appliances, and motors, and will consequently improve consumer relations.

Therefore, benefits derived justify optimum precision in the application and setting of regulators.

Powering Business Worldwide

Functions Of The Automatic Controls

A regulator is equipped with a solid-state voltage-sensing circuit (VSC) that has a voltage balance point and that causes the regulator to change taps to maintain a constant base voltage (usually 120 volts) at its input terminals. This voltage (without compensation) is equal to the line voltage divided by the control winding primary-to-secondary ratio. Main connections of the regulator and of the control winding are illustrated in Figure 1.

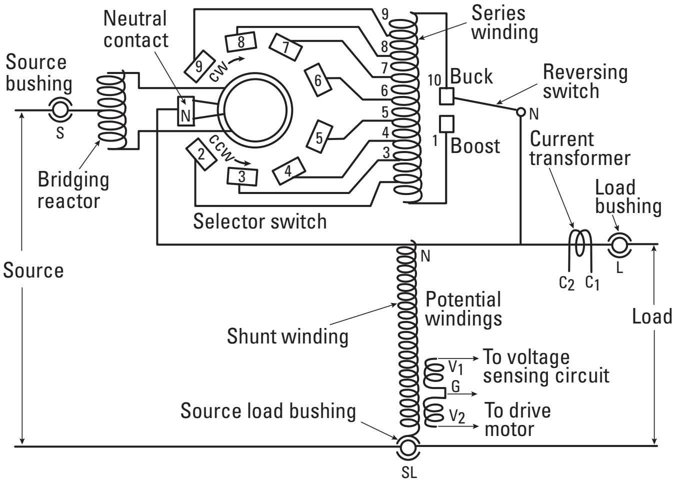


Figure 1. Schematic of main connections for a single-phase regulator.

The compensator, essentially an artificial line containing adjustable resistance and reactance elements, is connected to the secondary terminals of a line current transformer. Thus, it can be set to reproduce a miniature replica of voltage drop in the power circuit. This voltage is connected to subtract vectorially from the miniature primary voltage supplied to the voltage-sensing circuit. In order to balance, the VSC will cause tap changes until an amount equal to the calculated feeder voltage drop. The control connections described are basically illustrated in Figure 2.

Setting the compensator at the correct R and X values to duplicate line conditions is accomplished by adjustment of clearly marked dials as described in instructions of the control unit. Methods that can be used in making necessary voltage-drop calculations and converting them to compensator settings are subsequently described.

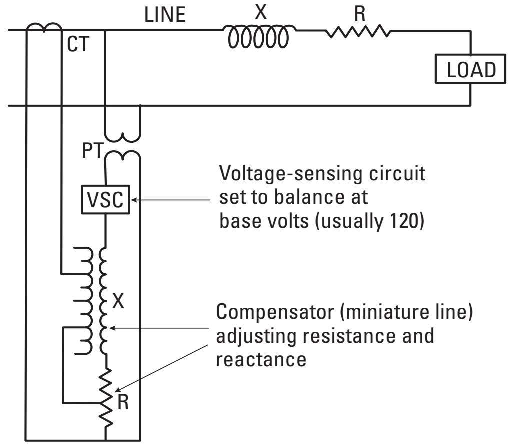


Figure 2. Simplified connections of compensator and voltage relay.

Approach For Determination Of Settings

Accurate setting of the voltage-sensing circuit (VSC) is essential. This VSC acts as the reference standard for circuit voltage control. It can be shown that a narrow band (within practical limits) between raise and lower contact-closing points results in the greatest benefits from automatic feeder voltage regulation. Bandwidth is a constant that adds to the line-drop range and increases the total voltage variation at any point.

Determination of circuit voltage drop, the basis of compensator settings, is most readily accomplished in increments because circuit characteristics and loads along the circuit are nonuniform. A typical distribution circuit problem is illustrated by the schematic diagram and voltage profile of Figure 3.

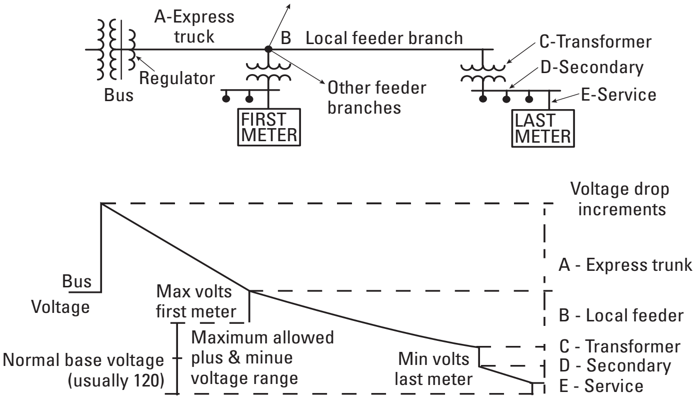


Figure 3. Typical feeder layout and voltage

The schematic and profile show that, for the case illustrated, the total circuit voltage drop is made up of five increments, A through E, which should be considered separately. Under loaded conditions, it will be noted that the voltage between the first and the last service meters graduates from maximum to minimum values on each side of the nominal base value, usually 120 volts, at the center of regulation. The range from maximum to minimum values is a function of circuit design and loading. Limits allowed are set by economic and other policies established locally.

There is some point on the circuit where, as the load varies throughout its cycle, the voltage can be held approximately at constant base value. At any load, the maximum over voltages and corresponding under voltages along the feeder remain substantially equal if the load varies uniformly. The voltage drop to the point mentioned, i.e., the center of regulation (rather than the center of load), is translated into regulator compensator values set to continuously maintain these voltage conditions.

Making The Voltage-Drop Calculations

Determination of voltage drop to the regulation center poses special problems in every case; however, advantage may be taken of similarities and simplifications. On the other hand, there are circuit and load conditions that are incompatible with desirable regulation. These must be rationalized or corrected.

Following, by means of a general example, is a guide for making voltage drop calculations. Each circuit, whether for distribution or transmission purposes, should be analyzed increment by increment to determine how each should be treated. The example is the distribution feeder illustrated by Figure 3.

1. Basic Conditions

To a practical degree, it is desirable that the loads connected along the circuit be similar in character. They should vary in a similar way—both in magnitude and power factor—throughout load cycles; for example, it would be undesirable to have a large amount of power load on one branch and a predominance of lighting load on another.

The location of power-factor-correction capacitors may be of critical importance. For example, if such capacitors are distributed over the circuit, satisfactory regulation may be accomplished; whereas, a bank located close to and on the load side of the regulator would result in false line-drop compensation. Similarly, cable in the circuit has relatively high capacitance that must be considered. The line current flowing in miniature through the compensator would be of a different magnitude and power factor than that flowing through the circuit impedances. Compensator settings would have to be established by a compromise such as described in the APPROACH FOR DETERMINATION OF SETTINGS section.

It is assumed, for the purpose of the following outline and discussion, that the circuit layout and loading permit good voltage control. Refer to Figure 3 for the letter references contained in the following headings. Calculations are summarized in the REFERENCE SUMMARY section.

2. Express Trunk—A

Compensator setting will be simplified if line-drop calculations are based on the regulator current transformer primary rating. Calculate resistance and reactance drops separately. Calculated voltage drop values can then be converted more directly into compensator volts.

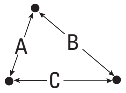
Table 1 provides impedance values for common open-wire circuits. Any cable of appreciable length must, of course, be taken into account. Also, any lumped reactance on the load side of the regulator, such as a current-limiting reactor, must be included.

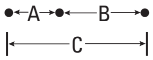
Table 1. Resistance and Reactance, Single-Conductor Values per 1000 ft. of Open-Wire Line.

Copper Size in Circular Mills or B&S Gage (Approx. for Al)	Resistance of One Conductor in Ohms per 1000 Ft. at 25 °C		REACTANCE at 60-cycle in ohms per 1000 feet of each conductor of a single-phase other arrangements of conductors, see Note. Reactance values are for concentric stranded copper conductors and are approximately correct for aluminum cable conductors.																		
			Symmetric-Spacing D Between Centers of Conductors (in.)																		
	Stranded Copper Hard; Drawn	Aluminum Cable Steel; Reinforced	4	6	8	12	15	18	21	24	27	30	33	36	40	48	60	72	84	96	108
750,000	.0155	.0252	054	.063	.069	.079	.064	.088	.092	.095	.098	.100	.102	.104	.108	.111	.116	.120	.124	.127	.129
700,000	.0165	.0265	055	.064	.070	.080	.085	.089	.093	.096	.099	.101	.103	.105	.109	.112	.117	.121	.125	.128	.130
600,000	.0195	.0299	057	.066	.072	.082	.087	.091	.095	.098	.100	.103	.105	.107	.111	.114	.119	.123	.127	.130	.132
500,000	.0227	.0354	059	.068	.074	.064	.089	.093	.097	.100	.102	.105	.107	.109	.113	.116	.121	.125	.129	.132	.134
400,000	.0280	.0445	062	.071	.077	.087	.092	.096	.099	.103	.105	.108	.110	.112	.115	.119	.124	.128	.131	.135	.137
350,000	.0320	.0526	063	.072	.078	.088	.093	.098	.101	.104	.107	.110	.112	.114	.117	.120	.125	.130	.133	.136	.139
300,000	.0371	.0588	065	.074	.081	.090	.095	.099	.103	.106	.109	.111	.113	.115	.119	.122	.127	.131	.135	.138	.140
250,000	.0445	.0662	067	.076	.083	.092	.097	.101	.105	.108	.111	.113	.115	.117	.121	.124	.129	.133	.137	.140	.143
0000	.0527	.0881	070	.079	.086	.095	.100	.105	.108	.111	.114	.116	.118	.121	.124	.127	.132	.137	.140	.143	.146
000	.0662	.1118	073	.082	.089	.098	.103	.107	.111	.114	.117	.119	.121	.123	.127	.131	.135	.139	.144	.146	.148
00	.0833	.1363	075	.085	.091	.100	.106	.110	.114	.117	.119	.122	.124	.126	.129	.133	.138	.142	.146	.148	.151
0	.1051	.1705	078	.087	.094	.103	.109	.113	.116	.119	.122	.124	.127	.129	.132	.135	.140	.144	.148	.151	.154
1	.132	.210	081	.091	.097	.106	.111	.115	.119	.122	.125	.127	.129	.131	.135	.138	.143	.146	.151	.154	.156
2	.167	.267	083	.093	.099	.109	.114	.118	.121	.125	.127	.130	.132	.134	.137	.140	.146	.150	.153	.156	.159
4	.267	.424	089	.098	.105	.114	.119	.123	.127	.130	.132	.135	.137	.139	.143	.146	.151	.155	.159	.162	.165
6	.422	.674	094	.103	.110	.120	.124	.129	.132	.135	.138	.140	.141	.145	.148	.151	.156	.161	.164	.167	.170

NOTE: Geometric Mean Distance (GMD), D for any three-phase conductor arrangement.

$$D = \sqrt[3]{A \times B \times C}$$





3. Local Feeder—B

Since current in the local line tapers off toward the end, voltage drop along the feeder plots as a curve, as illustrated in Figure 3. Also, line conductor sizes may reduce toward the end of line. For these reasons, it usually is not feasible to find and calculate drop precisely to the regulation center. Approximations are necessary. These should be made using the same current base as used for the trunk.

An approximate solution, usually satisfactory where the load is fairly uniformly distributed, is to assume that 100% of the current flows as far as one-third the total length and that the load is concentrated at this point. Another premise for this is that the line characteristics are the same over the length of the branch. The results may be adjusted if there are significant deviations from the assumptions.

Should the circuit have two or more main radial branches, only a portion of the base load will be carried by each. Thus, the local branch-voltage drop will reduce accordingly. Should the load be split evenly three ways, for example, the current and, therefore, the voltage drop for each will be reduced to one-third.

4. Transformer—C

Obviously, individual transformer loads and impedances will vary quite widely. However, transformer regulation is usually not a major portion of the total. Therefore, a flat rule may apply.

The average impedance Z of modern transformers in sizes mounted on poles may be taken as about 2%; also X may be taken as equal to R. On this premise, and assuming that transformer load is 100% at the time of the base load used for line calculations, the allowance for the transformers will be 1.4% resistance and 1.4% reactance volts drop. These come from the above transformer values where Z = 2 and R = X; i.e., R or X = √2. Appropriate adjustments can be made by ratio for any other percent load.

To combine properly with calculated line values, the voltage drop must be correctly converted to volts on the primary side of the transformer.

5. Secondaries and Services—D and E

By calculation, average voltage drops for the secondaries and services should be approximated. The combined total may approximate 2%, each, R and X voltage drops, if these circuits are open-wire. Values used will be influenced by local circuit design (such as the use of triplex cable) and loading practices. If Table 1 is used, the drop calculated will be the per conductor value. Therefore, if the service is three-wire, 120/240 volts, for example, the percentage is calculated using a 120-volt base.

The percentages R and X are translated into primary terms, following the method used for the transformer. The percentage values may be combined with the transformer values so only one conversion is involved.

6. Summary

If based on the impedance in Table 1, the primary line voltage drop values (for A and B, Figure 3) are on a single-conductor basis. Thus, they are in basic form to be converted for the particular type of circuit and regulator connection (see CONVERSION TO COMPENSATION SETTINGS section). The transformer and secondary percent impedance values (C, D, and E) are multiplied by the transformer primary voltage rating to obtain equivalent volts drop. It is assumed for Table 2 (multipliers) that local service transformers are phase-to-neutral connected on four-wire wye systems and phase-to-phase connected on three-wire delta systems.

Table 2. R and X Voltage-Drop Multipliers

Portion of Circuit (Figure 3)	Single Phase of Wye	Single Phase of Delta	Three-Phase Wye	Three-Phase Delta
A+B	2*	2	1	√3
C+D+E	1	1	1	1

*Assumes that the entire load current returns through the neutral wire. Multiple grounding can reduce the value to near 1.5.

Resistance and reactance voltage drop values from Table 2 will be in a form to convert, either combined or separately, to regulator compensator settings. In practice, it may be feasible to calculate for each circuit only the primary line values, and to develop standard values for the local transformer and secondary circuits.

The CONVERSION TO COMPENSATOR SETTINGS section contains a complete summary for reference when determining settings for a specific circuit.

Effect Of Shunt-Capacitor Loads

The effect of shunt-connected capacitors on VSC and compensator settings depends to a great extent on where they are connected. Capacitor loads can reduce the effectiveness of compensation. Distribution of the capacitor and service loads over the circuit usually differs; also, capacitor loads remain constant, while the service loads vary.

Following are some combinations of conditions encountered in practice and modifications in settings that they suggest. Solving the problem for the maximum service load should produce acceptable results. If the maximum and minimum voltages (i.e., at the first and last meters) occurring under this condition are within established limits, then voltages at minimum load should normally be satisfactory. It is assumed that the amount of shunt capacitor load is within the bounds of good engineering practice; however, large amounts of cable may cause difficulty.

1. Distributed Capacitors

If there is a reasonable uniformity in the spread of capacitors, the power factor of the current will be substantially the same everywhere along the line. Then, power factor of the current causing voltage drop in the line would be close to that of current flowing in the compensator. Thus, setting calculations would be only slightly complicated.

Shunt capacitors are usually connected to the primary line. There, they do not reduce transformer or secondary voltage drop. The voltage drops in these elements of the total circuit would be slightly higher than they appear to be at the regulator. One method of approximating this is to add a small value, probably less than 1%, to the total of the calculated transformer and secondary voltage drop values.

Another approach is suggested by the fact that the capacitors cause a specific and constant reduction in voltage drop along the line regardless of variations in service load. Most of the reduction is due to the effect of a leading capacitor current flowing through the line reactance. To make use of this fact, the voltage improvement at the regulation center can be separately calculated for only the capacitor load without regard to the service load. Since this value is a constant, the increase in line voltage due to the capacitors can be translated into a reduction in the voltage setting of the voltage-sensing circuit. Then, the compensator values for the primary line must be calculated as if there were no capacitors. These values would be based on the original base kw load, but on a new kva (ampere) value corresponding to the service load power factor. That is, the voltage-drop values to be used for the primary line portion of compensator settings would be increased by the ratio of power factors with—and without—the capacitors:

$$\frac{\text{Power factor with capacitors}}{\text{Power factor without capacitors}} \quad \text{x} \quad \text{Original voltage-drop}$$

2. Lumped Capacitors

Capacitor banks of considerable size or a large amount of cable pose special problems, usually rationalized by compromise. Where fixed banks are installed at some distance out and on the feeder branches, the solution frequently may be treated as the above distributed capacitors.

Large concentrations of capacitance near, and on the load side of, the regulator should, if possible, be avoided. A compromise of setting values, determined with— and without—capacitors, would necessarily be required. The regulator compensator has no way of knowing that the capacitor current does not flow through the impedance of the line, thus it has no chance to improve the voltage along it. Another approach is to increase the VSC voltage setting by an amount equivalent to the rise in voltage that would have been caused by such capacitors had they been connected out on the line. This solution would, at full load result in correct voltage at the regulation center, but a check should be made for excessively high voltage at minimum load.

Switched capacitors, connected anywhere on the line, also require a compromise in determining compensator settings. Settings halfway between calculated requirements with—and without—the capacitors connected may prove to be a reasonable compromise.

Conversion To Compensator Settings

The line-drop compensator has adjustable resistance and reactance elements connected in series. Controls of each are marked in one-volt increments through 24 volts. (The resistance element actually is a rheostat that can be positioned between one-volt markings.) The voltage drop across each compensator element will be as marked *when primary current through the current transformer is at CT (not necessarily regulator) rated value*, listed in Table 3.

Table 3. Current Transformer Primary Ampere Values that Produce Dial-Marked Compensation Values

Regulator Current Ratings	CT Primary Current Ratings
25	25
50	50
75	75
100	100
150	150
167,200	200
219, 231, 250	250
289, 300	300
328, 334, 347, 400, 418	400
438, 463, 500, 548, 578, 656, 668	600
833	800
1000	1000
1332, 1665	1600

NOTE: Current transformer primary ampere value (CT ratios per nameplate) that results in 24 volts resistance and 24 volts reactance compensation, as marked on compensator dials. The current transformer value is appropriate for making voltage drop calculations, rather than the regulator rating.

The voltage across the compensator subtracts vectorially from the auxiliary control potential voltage. The resultant is applied to the voltage-sensing circuit, causing it to react as if it were at the center of regulation. Regulator and compensator connections are illustrated schematically in Figures 1 and 2.

The regulator will change taps until the voltage across the VSC is the nominal preset value, usually 120 volts. Without compensation, this will be exactly the primary voltage divided by the overall ratio of the control potential windings. This ratio can be changed by means of a secondary auxiliary transformer usually provided for special purposes. Overall control potential ratios, which must be used to obtain accuracy, are listed in Table 4.

Regulator Voltage Rating	Nominal Single-Phase Voltage	Ratio Adjusting Data		Nominal Control Setting*	Overall Potential Ratio*
		Int. Tap	Cont. Tap		
2500					
20:1	2500			125	20:1
	2400			120	20:1
5000					
40:1	5000	4.8	120	125	40:1
	4800	4.8	120	120	40:1
	4160	4.8	104	120	34.6:1
20:1	2400	2.4	120	120	20:1
7620					
60:1	7980	7.2	133	120	66.5:1
	7620	7.2	127	120	63.5:1
	7200	7.2	120	120	60:1
	4800	4.8	120	120	40:1
	4160	4.8	104	120	34.6:1
	2400	2.4	120	120	20:1
13800					
115:1	13800	13.8	120	120	115:1
	13200	13.8	115	120	110:1
	12000	13.8	104	120	100:1
57.5:1	7980	6.9	133	125	63.5:1
	7620	6.9	133	120	63.5:1
	7200	6.9	120	125	57.5:1
	6900	6.9	120	120	57.5:1
14400					
120:1	14400	14400	120	120	120:1
	13800	13800	115	120	115:1
	13200	13200	110	120	110:1
	12000	12000	104	115	104:1
60:1	7980	7980	133	120	66.5:1
	7620	7620	127	120	63.5:1
	7200	7200	120	120	60:1
19920					
166:1	19920	19.9	120	120	166.1
120:1	14400	14.4	120	120	120:1
	13800	14.4	115	120	115:1
	13200	14.4	110	120	110:1
	12000	14.4	104	115	104:1
60:1	7980	7.2	133	120	66.5:1
	7620	7.2	127	120	63.5:1
	7200	7.2	120	120	60:1

*Nominal Control Setting and Overall Potential ratio may vary slightly from one regulator rating to another. See the regulator rating plate for determining the exact values.

From the above, it is evident that actual primary volts drop, calculated with current transformer full-load current as previously described, divided by the specific overall control voltage ratio, basically becomes the setting for the compensator. In addition, however, the type of circuit and regulator connections must be taken into account.

1. Single-phase Circuit Regulators

For either wye or delta systems supplying independently regulated single-phase circuits, the voltage-drop values are converted by potential ratio directly into compensator settings. The voltage-drop values used must include both supply and return conductors.

2. Three-phase Wye Circuit Regulators

A four-wire wye circuit, Figure 4, operates basically with the load current in phase with the phase-to-neutral voltage. Therefore, calculated circuit voltage-drop-to-neutral (one conductor) values can be converted directly to compensator settings. Calculations are the same whether regulation is by means of three single-phase regulators or a three phase unit.

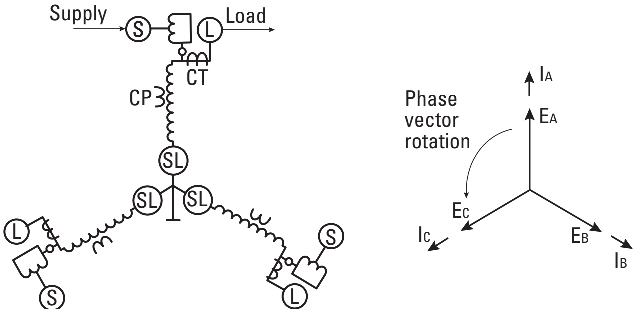


Figure 4. Four-wire,three-phase wye with three-phase or single-phase regulators.

3. Three-phase Delta Circuit Regulators

For three-wire-delta circuits, only if regulator windings are wye connected and neutrals are stabilized can compensators be set with voltage-drop values converted directly, using the control potential ratio. For such regulator compensation, all voltage-drop calculations (including transformers and secondaries) would have to be treated as if the load was wye connected.

For single-phase regulators connected either closed delta (Figure 5 and Figure 6) or open delta (Figure 7 and Figure 8), an extra step is required in making compensator settings. This is because the control potentials are in phase with the line-to-line voltages; whereas, the load currents are basically in phase with hypothetical, 30-degree displaced, line-to-neutral voltages.

Assuming 100% power-factor load, the line current is 30 degrees out of phase with the line-to-line voltage. Therefore, the compensator voltages would be shifted 30 degrees from the control voltage. The direction of shift may be either lead or lag, depending on regulator connections. It will be noted in Figures 5 and 6 that, with three regulators in closed delta, phase relations for all three regulators will be the same whether lead or lag; whereas, with two regulators in open delta, one will lead and one will lag.

As a result of the 30-degree phase displacement the magnitude of the compensator resistance and reactance values must be adjusted.

It has been proved that compensation values can be mathematically adjusted to artificially correct both phase angle and magnitude discrepancies, and these corrections will hold for any load power factor. The same corrections, to be made for either closed-delta or open delta regulator connections, are obtained with the following equations:

$R_1 = 0.866\ R - 0.5X$ and $X_1 = 0.866\ X + 0.5\ R$ for lagging unit

$R_2 = 0.866\ R + 0.5X$ and $X_2 = 0.866\ X - 0.5\ R$ for leading unit

NOTE: The above calculations can be quickly made by using Figure 9 on page 8.

Should any resistance or reactance value calculated with the equations prove to have a negative sign, then the effect of that element must be reversed. Reference must be made to the control instruction manual for the method of reversing the resistance compensation and for reversing the reactance compensation.

Compensator resistance/reactance settings for delta connected regulators differ based on the vintage of the control, as follows:

Key-entry Controls: McGraw-Edison (Cooper) CL4- series controls and newer require that the regulator configuration (Function Code 41) be entered. Compensator settings for these controls must be the unadjusted R and X values for a wye (star) system. Based on the programmed value of Function Code 41 (delta lead or delta lag) these newer controls automatically calculate the R_1 and X_1 or R_2 and X_2, and use the appropriate values in the LDC function.

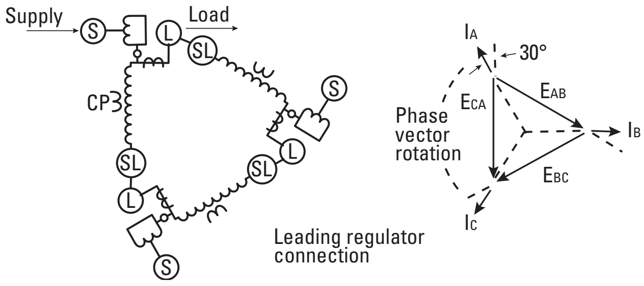


Figure 5. Three-phase, closed-delta connection—Case 1.

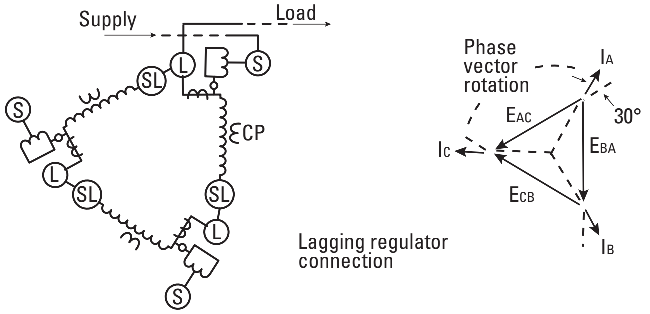


Figure 6. Three-Phase, closed-delta connection—Case 2.

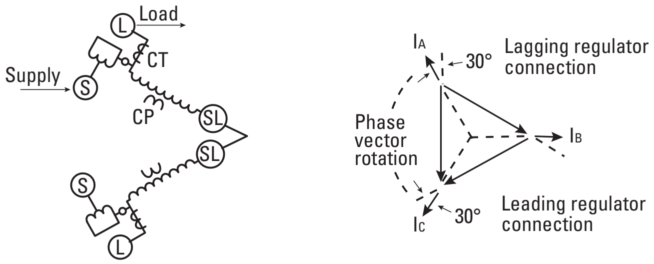


Figure 7. Three-phase, open-delta connection—Case 1.

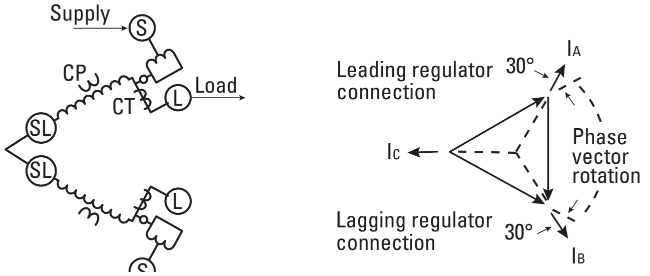


Figure 8. Three-Phase, open-delta connection—Case 2.

Dial-type Controls: McGraw-Edison (Cooper) CL-2A controls and older do not allow for the programming of the regulator configuration, therefore, the resistance and reactance settings on these controls must be the adjusted values of R_1 and X_1 or R_2 and X_2, as calculated above.

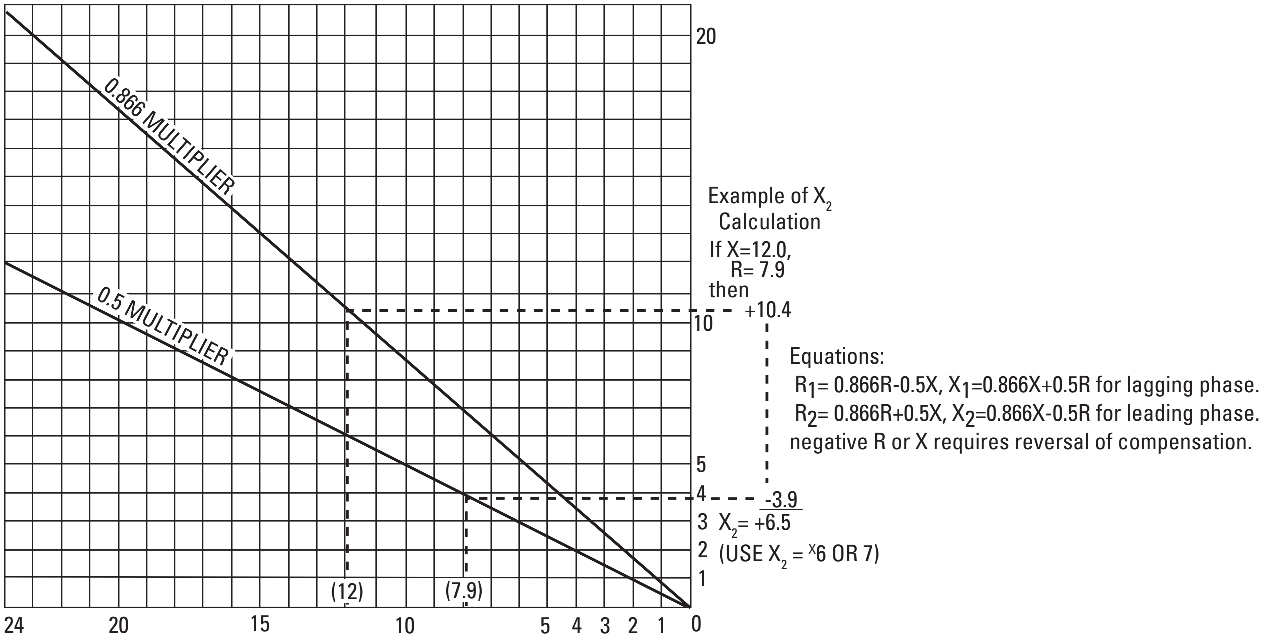


Figure 9. Chart and formulas for converting compensator settings to values for delta-connected regulators.

NOTE: It is not the purpose here to discuss the relative merits of various regulator connections. However, it may be noted that (a) current transformers of closed delta regulators are inside the delta, causing up to 10% error In compensation (under compensation); (b) a phase rotation results at any position but neutral with closed-delta banks, but not with open-delta banks; (c) closed delta banks provide 50% more voltage regulation range than open delta (15% instead of 10%); (d) there is some loss in kva capacity with delta connections because of load phase angle (inherent 30 degrees from regulator).

Reference Summary And Example

The MAKING THE VOLTAGE-DROP CALCULATIONS, EFFECT OF SHUNT-CAPACITOR LOADS, and CONVERSION TO COMPENSATOR SETTINGS sections contain general instructions for determining compensator settings that will be of optimum value. For the purpose of this summary section, it is assumed that the basic principles used for calculations are understood.

1. Step-by-Step Calculations

By the example and solution below, the procedure outlined in MAKING THE VOLTAGE-DROP CALCULATIONS section is illustrated.

Conditions

Circuit: Three-wire delta, 2400-volt.

Regulators: Two 300 amp in open delta.

Primary: Express—2000 ft., 4/0 Cu., at 36 in. GMD; branches—two with equal loads evenly distributed, each total 3000 ft., 2/0 CU., at 36 in. GMD.

Transformers: Assumes average impedance 1.4% *R*, 1.4% *X* and 100% load when regulator CT fully loaded.

Secondaries and Services: Assume 2% *R* and 2% *X* voltage drop when regulator CT is 100% loaded.

Solution

1. From Table 1, express *R* = .0527 and *X* = .121 ohms per 1000 ft. for a total *R* = .105 and *X* = .242 ohms. At 300 amps CT primary rating (listed for regulator in Table 3) per-conductor volts drop in *R* = 31.6 and in *X* = 72.6.
2. From Table 1, Branch *R* = .0833 and *X* = .126 ohms per 1000 ft. At 150 amps per branch to regulation center, one-third out on branch length, voltage drop in *R* = 12.5 and in *X* = 18.9.
3. Summarizing primary feeder, *R* = 44.1 and *X* = 91.5 volts per wire or to neutral. For a delta circuit, this converts—phase-to-phase-to— *R* = 76.4 and *X* = 158.5 volts (from V-6, multipliers equal 1 for wye, √3 for delta, and 1.5 to 2 for single-phase).
4. To convert 3 to control voltage level, divide by the overall potential ratio from Table 4; in this case, 20/1. The result is *R* = 3.8 and *X* = 7.9 volts.
5. Summarizing transformer and secondary drops, using assumptions: *R* = 3.4% and X = 3.4% or 81.6 *R* and 81.6 X volts at the 2400 volt primary rating. By potential ratio division, this becomes *R* = 4.1 and *X* = 4.1 at control voltage level.

   Note that these values may be large and important relative to the primary line drop; therefore, a very careful analysis to determine average circuit conditions is justified.
6. Adding **4** and **5**, *R* = 7.9 and *X* = 12.0 volts, total base control-level voltages.
7. Since this is a delta circuit with open-delta-connected regulators, the *R* and *X* settings are determined by artificial adjustment of the calculated voltages 6, using the chart, Figure 9. (For single-phase and four-wire, three-phase circuits, settings would be the calculated values of 6.) The chart shows a sample calculation.

If final setting calculations for delta regulators should be negative, it will be necessary to reverse the particular compensator element, as discussed in CONVERSION TO COMPENSATOR SETTINGS, Item 3.

2. Short Cut with Table

For convenience, calculations covered by Steps 1, 2, 3, and 4 in the step-by-step calculations are consolidated into a multiplier table, . The correct multiplier times line impedance provides, in one step, the basic voltage for setting the compensator. Above Steps 5, 6, and 7 in the step-by-step calculations must be followed as described.

For the branch primary calculation (Step 2), the multiplier must be selected according to the equivalent current transformer rating; i.e., corresponding to the actual branch load (150 amps for the example). Table 5 cannot be used without correction if the potential ratio is other than listed. The summations of the values for the express trunk (Step 1) and branch (Step 2) are necessarily made at the control voltage level.

DETERMINING LEADING AND LAGGING REGULATORS

A leading regulator of closed- or open-delta-connected banks is that unit in which 100% power-factor line load current (measured at the current transformer) leads the regulator voltage (measured at the control potential) by 30 degrees. In the lagging unit, the current lags the voltage by 30 degrees.

1. Phase Relations Known

If the phase rotation and identification of the circuit are known, units which are leading and units which are lagging can be identified by reference to Figure 5 through 8. The same relations hold, of course, should phase identifications (vector markings) in any diagram be rotated, provided the same phase order is retained.

2. Field Check for Rotation

Phase rotation, if unknown, can be determined in the field by the action of the individual regulators in an open-delta-connected bank when the reactance compensation is changed. If the bank is to be connected in closed delta, an open-delta connection may be made until phase rotation is determined or the SL terminal of one regulator can be transferred temporarily to the third phase for comparison.

With an open-delta connection, and a substantially balanced, sizable load of any power factor, *the voltage (or tap position) of the lagging regulator will increase the most* when the reactance compensation values are increased equally. Starting with zero R and X compensation, increase the X compensation value of each equally, until the difference in the voltage change is sufficient to be positively recognized.

Table 5
Multipliers for Direct Translations of Line Impedance to Compensator Settings

Nameplate Ratings		CT Primary Amps	Multiplier for Type Of Circuit Connection		
Volts	**KVA**		**Wye (Base)**	**Single (2 x Base)**	**Delta (v3 x Base)**
2500 Operating 2400 with 20/1 CP	25	100	5.00	10.00	12.98
	50 75	200 300	10.00 15.00	20.00 30.00	17.30 25.95
	100 125	400 600	20.00 30.00	40.00 60.00	34.60 51.96
	167 250	600 1000	30.00 50.00	60.00 100.00	51.96 86.60
	333 416.6	1600 1600	80.00 80.00	160.00 160.00	138.56 138.56
5000 Class Operating 4800 with 40/1 CP	25	50	1.25	2.50	2.17
	50 100	100 200	2.50 5.00	5.00 10.00	4.33 8.66
	125 167	250 400	6.25 10.00	12.50 20.00	10.83 17.32
	250 333	600 600	15.00 15.00	30.00 30.00	24.25 24.25
	41.6	800	20.00	40.00	34.64
7620 Class Operating 7200 with 60/1 CP	19.1 38.1	25 50	0.42 0.83	0.84 1.67	0.73 1.44
	57.2 76.2	75 100	1.25 1.67	2.50 3.33	2.17 2.89
	114.3 167	150 250	2.50 4.17	5.00 8.33	4.33 7.22
	250 333	400 600	6.67 10.00	13.33 20.00	11.55 17.32
	416.6 500	600 600	10.00 10.00	20.00 20.00	17.32 17.32
13800 Class Operating 13800 with 115/1 CP	69	50	0.43	0.87	0.75
	138 276	100 200	0.87 1.74	1.74 3.47	1.50 3.00
	414	300	2.61	5.21	4.50
14400 Class Operating 14400 with 120/1 CP	72 144	50 100	0.42 0.83	0.84 1.67	0.73 1.44
	288 333	200 250	1.67 2.08	3.33 4.17	2.89 3.60
	416 500	300 400	2.56 3.33	5.00 6.67	4.33 5.77
	5.76 667	400 600	3.33 4.17	6.67 8.33	5.77 7.22
	833	800	6.67	13.33	11.55
19920 Class Operating] 14400 with 166/1 CP	50 100	25 50	0.16 0.31	0.32 0.62	0.28 0.54
	200 333	100 200	0.63 1.25	1.25 2.50	1.09 2.17
	400 500	200 250	1.25 1.50	2.50 3.00	2.17 2.60
	667 833	400 400	2.50 2.50	5.00 5.00	4.33 4.33

Multipliers for other control potentials can be calculated by multiplying by the ratio shown over the new ratio times the value shown.

Exp: Wye (Base) for 76.2 kva, 7620 Class with 63.5/1

CP Ratio = 60/63.5 x 1.67 =1.58

UNGROUNDED-WYE CONNECTIONS

The conventional methods of connecting single-phase regulator banks is to use the grounded-neutral wye connection on a four-wire system and phase-to-phase connections on a three-wire system. When regulators are wye connected, it is normally necessary to stabilize the neutral by some means, this being accomplished by connection to the system neutral. If the common point (neutral) of the bank is not stabilized, it will shift electrically relative to the phase conductors, and voltages across individual units may vary widely.

If, for some reason, it is necessary to connect a regulator bank in wye, but isolate its neutral from the system, some special stabilizing provision is required. A practical method is to install a small grounding bank, consisting of three transformers, each from one-third to two-thirds the kva rating of the individual regulators. The rating within the range depends on the expected unbalance in load.

Three-phase regulators are normally designed for use on a four-wire system, with the regulator neutral grounded. Should it be necessary to isolate the regulator neutral, special provisions must be made. The neutral may be stabilized with a tertiary or by a grounding bank such as previously described.

Neutral shift may be tolerable when a three-phase regulator is supplying a substantially balanced load; however, special phase-to-phase instrumentation must be provided.

PARALLELING REGULATORS

Parallel operation of either three-phase or single-phase regulators necessitates some special provision to prevent off-step operation. This would cause the flow of excessive circulating current between regulators. If line-drop reactance compensation is used in the normal manner, the condition would become progressively worse because tap changes would be called for until the regulators run to opposite limits.

CAUTION

Under any circumstance, the impedance of regulators is too low to permit operation in direct parallel. Circulating current would be excessive even if they were only on tap off the same position. A parallel must have a loop impedance such as that provided when the regulators are inter-connected through different transformers.

There are several ways to prevent excessive off-step positioning of regulators operating in parallel. The most common, and one for which provision is built into the regulator control system, is to reverse the reactance compensation. Voltage drop through this element would then be in a direction to cause the regulators to change taps together.

A second method, for which provision is built into McGraw-Edison standard automatic control systems,is reactor paralleling—a method based on separation of load and circulating current. The circulating current, which is passed through all control units of the parallel, is used to operate the voltage-regulating relays and self-correct an off-position condition. Terminals of the multi-winding reactor coil are accessible at a control terminal block.

Other paralleling methods in use for special purposes can usually be worked into the normal control scheme.

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